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Multi-dimensional Modeling of Nova with Realistic Nuclear Physics

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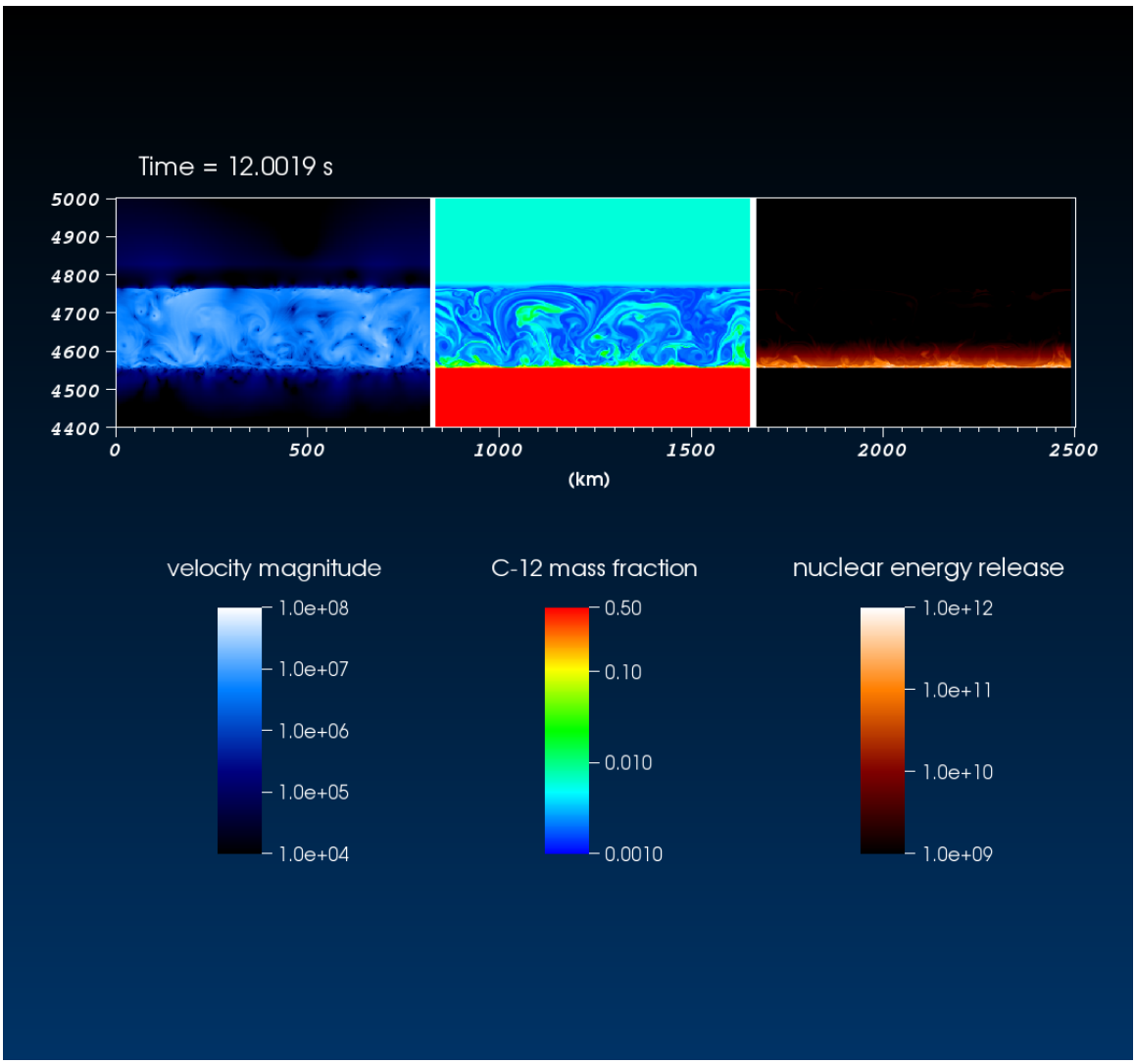
Over the past year, we continued our exploration of novae explosions through multidimensional simulations with the MAESTRO code. The basic physics needed for these simulations was already in place, but a lot of optimization and refining was needed to produce plausible models. Work focused both on the initial model and the reaction network, and simulations were performed using an NSF TeraGrid allocation on the Kraken machine.

The initial model we have been using for these simulations was provided by Ami Glasner. This model, produced with a 1-d Lagrangian stellar evolution code, needs to be modified to work with on the Eulerian grid that MAESTRO employs. While the basic process to convert this model was already in place at the start of this period, our simulations showed that the convective behavior is very sensitive to how the model is prepared. In particular, early MAESTRO simulations showed heating and large convective velocities high in the accreted atmosphere. The Mach number would eventually grow too large, breaking the regime of validity of these models. The graduate student working on these models, Brendan Krueger, was able to trace the development of these velocity features to a small "glitch" that followed from the Lagrangian griding in the entropy profile of the initial model provided to us.

We also explored the impact of thermal diffusion on our results. Previously published results (J. Casanova et al. 2010,2011) used thermal diffusion in their simulations, despite our expectation that the diffusion length scale would not be resolved on the grid. Our simulations showed that the impact of thermal diffusion was negligible, and therefore, subsequent simulations will be run without it.

We continued to explore resolution and found that the resolution needed to resolve the energy generation region is higher than that used in the Casanova et al. studies. This unfortunately means that the computational cost increases. As the major component of the computational cost for the 2-d simulations is the reaction network we turned our focus to optimizing the network.



Our simulations use the pphotcno network, made publicly available by Frank Timmes, which uses the ma28 linear algebra package together with a B-S integration routine to solve the system of ODEs that comprise the network. Experience with other networks in MAESTRO showed us that the commonly available VODE package provides robust and fast integration of networks, so we converted the pphotcno reaction network to use VODE. Initial results suggest a factor of 2 speed-up, which helps make the simulations more feasible.

Finally, an undergraduate student (Ryan Orvedahl) has been doing research with the PI for course credit over the last year. Ryan's project has been looking into a toy model for the nova (where we artificially generate the initial model by putting

an isentropic hydrogen atmosphere onto a white dwarf) and assessing whether the advection method that MAESTRO uses is robust in this case. A particular concern is that, in these nova models, the density jump from the white dwarf to the accreted hydrogen layer is quite large (owing to the change in the mean molecular weight). Although we smooth this out over some physical length scale in the preparation of the initial model, this still presents a steep gradient to the advection algorithm. The additional complication with the nova problem is that any errors in the advection at this interface can lead to artificially high reaction rates, since the underlying carbon mixed into the hydrogen layer catalyzes the CNO reactions. Our concern is how can we tell if the mixing we see at the hydrogen layer / white dwarf interface is physical, or artificially induced. To explore this better, we've been trying many variations of the advection scheme in MAESTRO. In performing the advection, MAESTRO needs to predict edge-centered states for computing fluxes through the zones from the cell-centered data that we store and evolve in our simulation. This is the standard way a finite-volume / Godunov code works. In predicting these edge centered quantities, there are a variety of analytically-equivalent set of combinations of variables one can work with (for instance, predict density * mass fraction as a single quantity or present density and mass fraction separately). These variations behave differently numerically, and can lead to different amounts of mixing. Ryan has been running MAESTRO with a variety of different methods of predicting the species to the interface, and presently has been exploring the same for the enthalpy. Some methods look a lot better behaved than others, and we are currently trying to understand these differences. To aid in the comparisons, Ryan is also running the toy nova problem with a compressible code, CASTRO.

Currently, nova simulations with MAESTRO are running. While the current results look good, and we are able to simulate for timescales comparable to those in the literature, we are still assessing whether there are any remaining problems with either the algorithm or initial models. We plan to continually have nova models running (and, in fact, have just been awarded an additional 2 million hours through TeraGrid to do so). Our current results will be presented at the upcoming winter AAS meeting in Austin, TX by Brendan Krueger.